Mechanical Engineering and Business Economics

Bachelor Thesis

Technologies for the next generation of production systems

Description of Cyber-Physical Systems, the Internet of Things and Smart Factory, and initiatives developed to promote their implementation

1332003 Blanca Bertran Subirana

Graz University of Technology

Institute of Production Science and Management

Dipl.-Ing. Alexander Pointner

Graz, June 2014

Statutory Declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

....

date signature

Abstract

The development and implementation of the last technological progresses is driving an evolution in different areas, making many of our daily tasks easier.
In the production field the progress of new technological systems such as *Cyber-Physical Systems* or *Internet of Things* is helping to create the so-called 'factories of the future', also known as *Smart Factories*. Some governmental initiatives developed in several countries are encouraging the implementation of these technologies in industry.
This paper describes the main characteristics of *Cyber-Physical Systems*, *Internet of Things* and *Smart Factories*, as well as clears up the relation established between these concepts. It also explains the main objectives of the *Industry 4.0* initiative, developed by the German government; and takes also an in-depth look at the *Advanced Manufacturing Partnership* (AMP) initiative, promoted by the U.E government to bring the country back to a leadership position in manufacturing activities.

Table of Contents

1 Introduction

The continuous evolution of computing and networking technologies is creating a new world populated by many sensors on physical and social environments. Basic aspects of this new world are Cyber-Physical Systems (CPS), integrations of computation, networking, and physical processes, and Internet of Things (IoT), interconnected devices, objects and things enabling interaction with physical environment. Their importance is growing in the production field, where many research projects are being developed in order to facilitate the integration of these technologies in manufacturing systems. Smart factories are starting to emerge due to the implementation of these novel systems. All this is driving to a new generation of production systems which are more flexible and efficient, and allow us to speed up planning and setup, to adapt to rapid product changes during operation, and to reduce the planning effort.

But still lot of research and development is needed in order to change the actual manufacturing system and make the 'fourth industrial revolution', as experts refers to this phenomenon, a reality.

This is a bibliographic work based on the collection and analysis of literature related to the topics, focusing on manufacturing and production systems. Its purpose is to give a general overview of the general characteristics of these technologies and in particular their potential concerning manufacturing industry. Such is the importance of CPS, Internet of things and smart factory in this field that governments of several countries are promoting different initiatives which aim to make next generation of production systems a reality. This paper describes also the objectives of Industire 4.0 and American Manufacturing Partnership (AMP), initiatives developed by the German and American government respectively, as well as the research areas they are working on.

The reminder of this paper is organized as follows. In Section 2 the Cyber-Physical Systems concept is introduced and aspects of their design as well as come application and research areas are explained. Section 3 describes the Internet of Things in a similar way. The idea behind the concept, the technological enablers, some applications and research challenges are discussed in this section. Section 4 focuses on the Smart Factory concept. Here different visions of the concept are reported, as well as the technological enablers and the SmartFactory initiative. In

Section 5 the Industry 4.0 concept is introduced and the initiative of the German government of the same name is explained. The initiative adopted by the American government is thoroughly described in section 6. Section 7 gives an overview of the production ramp-up concept. Finally, section 8 concludes this work by explaining the connections between the concepts described in previous sections.

2 Cyber Physical Systems (CPS)

In the book 'Applied Cyber-Physical Systems' Jim Brodie Brazell formulates the following definition for Cyber-physical systems (CPS)[1]:

> *"Cyber-physical systems utilize information technology (computers, software, and networks) to direct the communication and control of physical processes and systems (or vice versa). Cyber-physical systems include legacy analog and digital systems such as supervisory control and data acquisition (SCADA), machine-to-machine (M2M) computing, industrial control, and generally, all embedded systems utilizing automatic control techniques."*

In other words, cyber-physical systems are systems of collaborating computational elements controlling physical entities. CPSs integrate computing, communication and control with the real physical world.[2] Due to this close communication with surrounding physical environment and the unpredictable nature of the world, the complexity of the system is increased. Therefore, designing a multidisciplinary, concurrent, and distributed system should be considered.[3] Figure 1 shows an illustration of the flow among CPS.

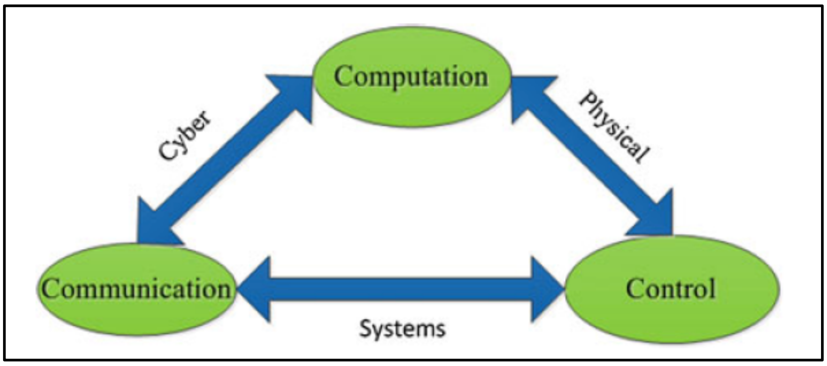

Figure 1: CPS integration overview[4]

Over the past century, many purely mechanical devices have evolved into computer-controlled and networked electromechanical systems.[5] Since then, those systems have appeared in many industries, including transportation, communication, entertainment and manufacturing.[6]

[1] Brazell (2014) p.7
[2] Wan, et.al. (2011) p.1
[3] Togay (2014) p.85
[4] Tanik, Begley (2014) p.130
[5] Broy, Schmidt (2014) p.70
[6] Broy, Schmidt (2014) p.71

The potential of CPS systems in economics and society is vastly grater than first realized, and major investments are being made worldwide to develop the technology. The German government, for example, is promoting the so-called ”fourth industrial revolution” initiative (Industry 4.0), which aims to introduce CPS systems into traditional industries.[7] (See section 5)

Cyber-physical systems are expected to play a major role in the design and development of future engineering systems with new capabilities that far exceed today’s levels of autonomy, functionality, usability, reliability, and cyber security.[8]

2.1 Design of CPS

The following is a list of the CPSs’ properties that should be considered during their design:[9]

- Tightly integrated: Physical entities are closely integrated with computation.
- Networked: Entities interact and are connected to each other through a network.
- Adaptability: Entities should have capability to reconfigure.
- Automation: Entities should have automation capability and CPSs should adapt itself to new situations.
- Distributed: Resources and entities are spread on the environment.
- Time awareness: Cyber-physical components have to succeed their tasks in a specific time range.
- Dependability: CPSs should be dependable (reliable, maintainable, available, safe, and secure) since services failures should be less than acceptable ranges.
- Predictability/Determinism: each entity should provide services in a predictable way in terms of time, used resources, and effect to environment.

When designing and improving CPSs, it is also important that designers get a feedback from the users. This can help to change the traditional relationship between users and product manufacturers. A user-centric engineering process is necessary to get explicit and implicit information from the customers. This method is based on observation of the human-computer interaction for a later analysis to detect inconvenient or undesirable interactions, design space exploration to find

[7] Broy, Schmidt (20149 p.71
[8] Baheti, Gill (2011) p.166
[9] Togay (2014) p.89

ways to improve the user experience and finally adaptation, reconfiguration or redesign of the system.[10]

From a technical perspective, cyber-physical systems are human-made artefacts that include:[11]

- Computing that controls mechanical activity through embedded processing
- Networking and connectivity
- Awareness of the environment and other objects through sensors
- A means of interacting with the environment through actuators

Efficient cyber-physical systems are based on the use of several computing technologies, networking, and physical processes working together. Embedded computers and networks monitor and control the physical processes, with feedback loops where physical processes affect computations and vice versa.[12]

These systems integrate the dynamics of the physical processes with those of the software and networking, providing abstractions and modelling, design and analysis techniques for the integrated whole.[13] Therefore, the design of such systems requires understanding the joint dynamics of computers, software, networks, and physical processes.[14]

Physical processes are compositions of many parallel processes. Measuring and controlling the dynamics of these processes by orchestrating actions that influence the processes are the main task of embedded systems. Consequently, concurrency is intrinsic in CPS. Many of the technical challenges in designing and analysing embedded software stem from the need to bridge an inherently sequential semantic with an intrinsically concurrent physical world.[15]

Studying models of systems gives insight into how those systems will behave in the physical world. Thus, modelling is an important part of the design of cyber physical systems. The use of models has a major advantage due to the formal properties that they can have. If the model is a good abstraction of the physical system, then the definitive assertion about the model gives confidence in the physical realization. Such confidence is hugely valuable, particularly for embedded systems where

[10] Broy, Schmidt (2014) p.72
[11] Broy, Schmidt (2014) p.71
[12] Derler, et.al. (2012) p.13
[13] Lee (2008) p.365
[14] Derler, et.al. (2012) p.13
[15] Derler, et.al. (2012) p.13

malfunctions can threaten human lives.[16]

When considering the design of software components, various physical world parameters such as time, memory and network should be taken into account, and also the nature of physical entities, such as actuators' response time.[17]

2.2 Applications

Applications of CPSs include medical devices and systems, assisted living, traffic control and safety, advanced automotive systems, process control, energy conservation, instrumentation, critical infrastructure, distributed robotics, weapons systems, manufacturing, distributed sensing command and control, smart structures, biosystems, and communications systems.[18]

It is easy to envision new capabilities that would have an enormous economic impact. Examples are distributed micro power generation, coupled into the power grid, and transportation systems which could benefit from better-embedded intelligence in automobiles and therefore improve safety and efficiency. Networked building control systems could significantly improve energy efficiency and demand variability, reducing our dependence on fossil fuels and our greenhouse gas emissions, and distributed real-time games that integrate sensors and actuators could change the nature of on-line social interactions.[19]

2.3 Cyber Physical Production Systems (CPPS)

Cyber Physical Production Systems (CPPS) are technologies made up of smart machines, logistics systems and production facilities that combine conventional production technology and IT (Information Technology), allowing machines and products to communicate with each other in the Internet of Things. They are a central topic in research and development in the production technology of the future that will determine the collaboration between machines and humans in assembly and production.[20]

The use of CPPSs leads to a fusion of information and planning systems with real production systems in horizontal and vertical direction. This poses new requirement

[16] Derler, et.al. (2012) p.13
[17] Togay (2014) p.85-86
[18] Wan, et.al. (2011) p.1
[19] Lee (2008) p.363
[20] http://www.awk-aachen.de/ [22-03-2014]

to producing companies: robustness with a simultaneous transformation ability of their production systems. Production systems with transformation abilities provide changes in case of need and dispose of deconstructing and extending functions as a crucial basis feature. It is expected from cyber physical production systems to enable this transformation ability and by this to make productivity potentials within a company accessible, to increase the level of resilience of the factories and to increase also the flexibility of production systems.[21]

As soon as a company tackles the evolution and use of CPPS, the productivity and transformation capability of the production system increases. This allows manufacturing companies to deal with changing customer requirements or a fluctuating quantity of purchase orders.[22]

2.4 Research challenges

Advances in CPS research can be accelerated by identifying needs, challenges, and opportunities in several industrial sectors and by encouraging multidisciplinary collaborative research between academia and industry. The objective is to develop new systems and engineering methods for building high-confidence systems in which cyber and physical designs are compatible, synergistic, and integrated at all scales.[23]

2.4.1 CPS itself

Given the huge differences between mechanical and software engineering, the transition from physical products to cyber-physical systems requires a fundamentally new engineering approach with its own set of challenges.[24] This evolution from mechanical systems to CPS systems is based on the gradually integration of computing hardware and software over time. Designers have to solve new challenges during each phase of the product development life cycle: from constraints to maintenance, including requirements and implementation.[25]

Other research challenges related to the CPSs are their robustness, safety and security, as well as their verification, validation and certification. Effort has to be put

[21] http://www.awk-aachen.de/ [22-03-2014]
[22] http://www.awk-aachen.de/ [22-03-2014]
[23] Baheti, Gill (2011) p.166
[24] Broy, Schmidt (2014) p.71
[25] Broy, Schmidt (2014) p.72

also on the development of models of CPS. These models are used to generate and test software implementations of control.[26]

2.4.2 Biomedical and Healthcare systems

CPSs have several applications in medicine and in biomedical engineering: from intelligent operating rooms and hospitals to image-guided surgery and therapy. Healthcare increasingly relies more on medical devices and systems that are networked and needed to match the needs of patients with special circumstances. Thus, research in medical and healthcare domain would be important in order to develop better devices that are dynamically reconfigured, distributed, and can interact with patients and caregivers in complex environments.[27]

2.4.3 Next-Generation Air Transportation Systems

CPSs research can also have a future impact on the design of future aircraft and air traffic management systems. In this area research is focused on technical challenges which involve verification and validation of complex flight-critical systems. The research in this field aims to promote reliable, secure, and safe use for next generation air transportation. As the complexity of systems increases, costs related to verification, validation, and safety assurance will also increase and therefore the cost of building next-generation vehicles would get higher.[28]

2.4.4 Smart Grid and Renewable Energy

The goal of the research in this field is to improve energy efficiency by investing in modernization of the energy infrastructure. The increasing demand for electricity is driving the development of renewable energy and smart grids. Future efforts will be needed to focus on data fusion and analysis for real-time dynamics monitoring, prediction, and system control. Advances in optimization of multi-scale dynamic systems as well as in distributed control are necessary to improve smart grid performance, referring to security, efficiency, reliability, and economic.[29]

[26] Rajkumar, et.al. (2010) p.734-735
[27] Baheti, Gill (2011) p.163
[28] Baheti, Gill (2011) p.164
[29] Baheti, Gill (2011) p.165

3 Internet of Things (IoT)

The Internet of Things (IoT) is a computing concept that describes a future where everyday physical objects will be connected to the Internet and will be able to identify themselves to other devices. The term is closely identified with RFID as the method of communication, although it also may include other sensor technologies, wireless technologies or QR codes.[30]
The term IoT was first coined by Kevin Ashton in 1999 in the context of supply chain management. However, in the past decade the definition has been more inclusive covering wide range of applications.[31] (See section 3.2)
The Internet of Things is a combination of technological push and a human pull for more and ever-increasing connectivity with anything happening in the immediate and wider environment. This push-pull combination makes the development of Internet of things very strong, unstoppable, fast and extremely disruptive.[32]
Thus, it is predictable that within the next decade the Internet will exist as a seamless fabric of classic networks and networked objects. Content and services will be all around us, always available, paving the way to new applications, enabling new ways of working, new ways of interacting, new ways of entertainment and new ways of living. This innovation will be allowed by the embedding of electronics into everyday physical objects, making them ‘‘smart’’ and letting them seamlessly integrate within the global resulting cyber-physical infrastructure.[33]

3.1 Idea behind the Internet of Things

The key idea behind the IoT concept resides in the huge potential of embedding computing and communication capabilities into objects of common use. However, the identification of objects, based on the RFID technology, as well as the interaction of them with the physical environment, allowable by sensors and actuators, are additional features that should also be properly accounted for.[34]

[30] http://www.techopedia.com/ [14-04-2014]
[31] Gubbi, et.al. (2013) p.1645
[32] Kramp, et.al. (2013) p.2
[33] Miorandi, et.al. (2012) p.1497
[34] Miorandi, et.al. (2012) p.1502

The main characteristics of the IoT can be briefly resumed as:[35]

- Anything communicates: Smart things have the ability to wirelessly communicate among themselves through networks of interconnected objects.
- Anything is identified: Smart things are identified with a digital name that permits the specification of relationships among things whenever physical interconnection cannot be established.
- Anything interacts: Smart things can interact with the local environment through sensing and actuation capabilities whenever present.

The smart objects involved in the Internet of Things may have some technological capabilities in order to allow the communication, identification and interaction before mentioned. These capabilities are:[36]

- Identification: The transformation of physical into network nodes of the IoT requires a technique for unique identification. This identification allows the object to be linked with services and data that are stored on a remote server in the network.
- Memory: The object has to storage capacity so that it can carry information on its past or future. Storage capacity on the physical objects allows for the creation of highly decentralized systems with individual objects knowing the business processes they are involved in.
- Sensor technology: The object collects information about its environment, records it and reacts to it. Organizations can thus learn more about their products' usage processes and utilize this information for offering novel services or improve the design of their products.
- Position and tracking: Objects in the IoT may know their position or might be located by others. Information systems may thus reach out into the physical world and provide location-dependent services to users whenever and wherever they are needed.
- Processing logic: Objects may be able to make decision automatically without a central planning. Therefore, the IoT becomes not only an infrastructure for data collection, but rather offers the opportunity for

[35] Miorandi, et.al. (2012) p.1502
[36] Fleisch, et.al. (2009) p.99-100

changing the architecture of today's information systems by delegating decision-making authorities down to the outer edge of the network.

- Networking: Objects have the capability to connect with resources in a network or even amongst themselves for the reciprocal use of data and services.
- User interface: The merging of computer and physical world calls for new requirements that have to be met by the user interface. New approaches similar to the mouse and desktop metaphor of graphical user interfaces have to be found.

3.2 Technological enablers for IoT's use in production

The RFID technology and the wireless communication are two of the technological pillars of the Internet of Things. They have already been incorporated into a wide array of products and applications.[37]

The operation of an industrial plant using this technology starts when production parts reach the processing point and the RFID reader reads the tag. An event is generated by the reader with all the necessary data and stored on the network. The machine/robot gets notified by this event and picks up the production part. By matching data from the enterprise system and the RFID tag, it knows how to further process the part. In parallel, a wireless sensor mounted on the machine monitors the vibration and if it exceeds a specific threshold an event is raised to immediately stop the process. Once such an emergency event is propagated, devices that consume it react accordingly. The robot receives the emergency shutdown event and immediately stops its operation. The plant manager also immediately sees the status of the so called Enterprise Resource Planning (ERP) orders, the production progress, the device status, as well as a global view on all the elements and the possible side effects of a production line delay due to shop-floor device malfunctions.[38]

As showed, IoT technologies can provide enhanced flexibility in terms of reader positions, while at the same time enable seamless interoperability between RFID-based applications used by different actors, dealing with the product throughout

[37] Miorandi, et.al. (20129 p.1509

[38] Atzori, et.al. (2010) p.2795

the various phases of its life-cycle.[39]

3.3 Applications

Potentialities offered by the IoT make possible the development of a huge number of applications, of which only a very small part is currently available to our society. Applications of this technology reach many different areas. In the healthcare domain, IoT can be used for tracking of objects and people, identification and authentication of staff and patients and automatic data collection and sensing. Assisted driving, mobile ticketing and augmented maps are applications in the transportation and logistics domain. Referring to the smart environment domain, the intelligence of contained objects in an office, a home, an industrial plant or a leisure environment makes its ‘employment’ easy and comfortable. For the personal and social domain, applications of IoT enable the user to interact with other people to maintain and build social relationships. Social networking, historical queries and the prevention of losses and thieves are some examples of this area. [40]
In retail applications, IoT technologies can be used to monitor in real-time product availability and maintain accurate stock inventory. They can also play a role in after-market support, whereby users can automatically retrieve all data about the products they bought.[41]
The Internet of Things is also becoming prevalent in industry, where it connects real and virtual worlds of production. The fusion of these two worlds via the Internet enables manufacturers to connect all machines, products, and systems involved in the production process, allowing them to communicate with each other. Moreover, they can independently control each other.[42]
Next some of the most relevant applications of the Internet of Things are described more in detail, and particularly the role of this technology in each application is explained.

3.3.1 Transport and Logistics

In this field, IoT improves not only material flow systems but also the global positioning and automatic identification of load, as well as the energy efficiency,

[39] Miorandi, et.al. (2012) p.1510
[40] Atzori, et.al. (2010) p.2793
[41] Miorandi, et.al. (2012) p.1511
[42] http://www.bosch-si.com/ [15-04-2014]

what decreases energy consumption. It is expected to bring profound changes to the global supply chain via intelligent cargo movement. This will be achieved by means of continuous synchronisation of supply chain information, making it more transparent, visible and controllable, and enabling intelligent communication between people and cargo.[43]

3.3.2 The Smart Home

Future smart homes will be conscious about what happens inside a building, mainly impacting three aspects: resource usage, security and comfort. The goal is to achieve better levels of comfort while cutting overall expenditure. Moreover, smart homes also address security issues by means of complex security systems for detecting theft, fire or unauthorized entry. Different actors will cooperate in the user's home, such as Internet companies, device manufacturer, telecommunications operators, media service providers, and security companies, among others.[44]

3.3.3 Smart Cities

While the term smart city is still a fuzzy concept, there is a general agreement that it is an urban area that creates sustainable development and high quality of life. Characteristics of smart city include economy, people, governance, mobility, environment and living. Outperforming in these key areas can be achieved through strong human or social capital and ICT (Information Communication Technology) infrastructure.[45]

3.3.4 Smart Factory

IoT will provide automatic procedures that involve a drastic reduction in the number of employees needed. Workers will be replaced by bar code scanners, readers, sensors and actuators, and in the end by complex robots as efficient as human being. This and other technologies will bring opportunities for white-collar

[43] Kramp, et.al. (2013) p.3
[44] Kramp, et.al. (2013) p.3
[45] Kramp, et.al. (2013) p.3

workers and a large number of technicians will be required to program and repair these machines.[46]

3.3.5 Retail

IoT realises both customer needs and business needs: price comparison of a product; looking for other products of the same quality al lower prices; giving information about shop promotions not only to customers but also to shops and business. Having this information in real time helps enterprises to improve their business and to satisfy customer needs.[47]

3.3.6 E-Health

Control and prevention are two of the main goals of future health care. Nowadays, people have the option of being tracked and monitored by specialists even if they are not in the same place. Tracing people's health history is another aspect that makes IoT-assisted e-health very versatile. IoT makes human interaction much more efficient because it permits the localization, tracking and monitoring of patients.[48]

3.3.7 Smart energy and Smart Grid

In this scenario the key issue is to detect ways to save energy. Therefore, initiatives that imply more distributed energy production must be highlighted. The use of IoT platforms in smart metering will provide an efficient network of smart meters that allow for faster outage detection and restoration of service, grater control by customers over their energy or water consumption, and reducing the need for building power plants. Moreover, enterprises will be able to supply more efficient demand shaping.[49]

3.4 Research challenges

In order to turn the Internet-of-things from a concept into a well engineered, commercially viable technology paradigm, research challenges need to be

[46] Kramp, et.al. (2013) p.4
[47] Kramp, et.al. (2013) p.5
[48] Kramp, et.al. (2013) p.5
[49] Kramp, et.al. (2013) p.8-9

addressed to that topic. [50] A summary of the research areas classified by the need they are addressed can be seen in figure 2.

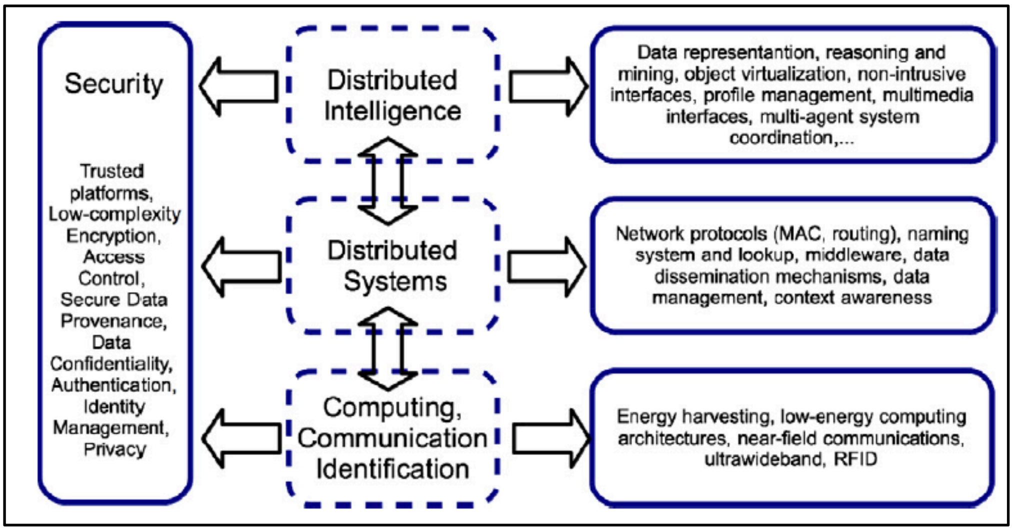

Figure 2: Classification of research areas relevant to the IoT[51]

The application of the IoT require the development of advanced techniques able to embed computing, communication and identification capabilities into every-day objects. The main challenge in this area is the need for an architecture supporting low-power, low-cost and fully networked and integrated devices fully compatible with standard communication technologies.[52]

The area of distributed systems technology includes aspects related to enabling objects to build a network, creating a distributed platform that enable the easy implementation of services on top. This builds on a traditional research line in computer science. The designs of architectures and protocols for distributed systems as well as the possibility to address objects using unique IDs are key issues for general networked systems and for IoT in particular.[53]

In the area of distributed intelligence, a challenging task is to interpret the huge amount of available data and reason about it. A related research field is that of distributed artificial intelligence, which addresses how autonomous software entities can be made able to interact with the environment and among themselves in such a way to effectively pursue a given global goal.[54]

Finally, research is also needed in security issues. Security represents a critical

[50] Miorandi, et.al. (2012) p.1502
[51] Miorandi, et.al. (2012) p.1502
[52] Miorandi, et.al. (2012) p.1502
[53] Miorandi, et.al. (2012) p.1503
[54] Miorandi, et.al. (2012) p.1504

component for enabling the widespread adoption of IoT technologies and applications. Without guarantees in terms of system-level confidentiality, authenticity and privacy the relevant stakeholders are unlikely to adopt IoT solutions on a large scale. Security considerations are orthogonal to other research areas, as illustrated in figure 2, so it is important to strive the research in this field.[55]

[55] Miorandi, et.al. (2012) p.1505

4 Smart Factory

Nowadays, many things such as phones, homes and cities are becoming *smart* due to the development of new devices and technologies that have the ability to check the system state updates and decide whether to act on it or not. In the field of production and manufacturing, smart factories are being developed and it is expected to be a reality in a near future.[56]

Following paradigms like Ubiquitous Computing and Internet of Things, modern factories are developing into intelligent environments in which the gap between the real and digital world is becoming smaller and smaller.[57] The Consequence is a Smart Factory that optimizes throughout the life cycle of the manufacturing systems by using data collecting and filtering technologies that blend into the environment.[58]

4.1 Visions of the concept

In the article 'A conceptual framework for the ubiquitous factory' the authors define the Smart Factory as "*a factory system in which autonomous and sustainable production takes place by gathering, exchanging and using information transparently anywhere anytime with networked interaction between man, machine, materials and systems, based on ubiquitous technology and manufacturing technology"* (See figure 3). This definition is based on the application of ubiquitous computing technology to the manufacturing system and therefore they denote the smart factory concept as U-Factory. The authors describe the information transparency, the autonomous control and the sustainable manufacturing as the main characteristics of the U-Factory.[59]

Another definition is given in the paper 'Smart Factory – towards a factory-of-things', which emerged from the SmartFactoryKL initiative (See section 4.3). This vision focuses more on a Smart Factory embedded in wireless communication infrastructure and is a way toward a factory-of-things, much more aligned with

[56] Radziwon, et.al. (2013) p.1186
[57] http://smartfactory.dfki.uni-kl.de/ [26-03-2014]
[58] Westkämper, Jendoubi (2003) p.1
[59] Yoon, et.al. (2012) p.2178

Internet-of-things (IoT).[60] The author points out that the prerequisites for smart factory are: a degree of intelligence embedded in all, even very small, coupled devices, while some of the important functionalities should be provided by RFID technology. A smart should not only have a modular structure, but also be interconnected by a wireless network, where each device could have its own IP address. Moreover, all those devices should be thoroughly tested to assure their safety and reliability before taking part in the creation of smart factory.[61]

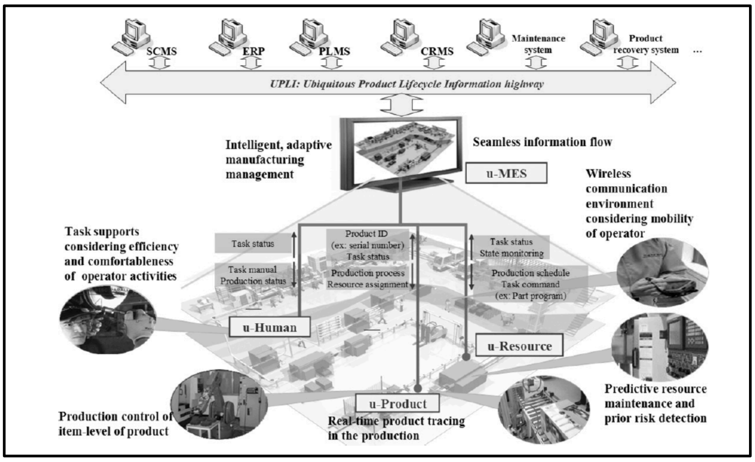

Figure 3: Conceptual model of U-Factory in *A conceptual framework for the ubiquitous factory*[62]

In the book 'Smart Factory - A Step towards the Next Generation of Manufacturing', another approach of the smart factory concept is given, based also on the study of the University of Stuttgart on the SmartFactory initiative. In their approach, the authors tried to interconnect a physical and a digital world. They define a smart factory as "*a factory that context-aware assists people and machines in execution of their tasks […] by systems working in background, so-called Calm-systems and context-aware applications." Context-awareness* refers to knowledge of position and status of objects of interest, where so-called *calm-systems* are its hardware and *context-aware applications* are the software. From their point of view, the real-time communication and interaction with smart environment is a key characteristic of the system and to do that, some wireless communication is necessary.[63]

A different vision of the concept is provided by researchers of the University of southern Denmark, who focus more on the factory function and propose a

[60] Radziwon, et.al. (2013) p.1186
[61] Zuehlke (2010) p.130
[62] Yoon, et.al. (2012) p.2179
[63] Lucke, et.al. (2008) p.115-118

decentralized supply chain setup. On a supply chain level, smart factories are characterized as self-sufficient facilities, which source raw materials from local suppliers. They suggest a local focus setup where a set of intelligent facilities – reconfigurable smart factories – would be able to completely supply a predefined area of market. They also propose a globalized approach that can be applied by large companies that not only operate in global markets, but also have many suppliers in different parts of the globe. This should help in decrease the delay, minimize inventory and at the same increase customization and responsiveness of the supply chain, due to proximity both to suppliers and customers.[64]

In an article called 'The dawn of the Smart Factory', published in the trade publication 'Industry Week', the author gives another definition of the smart factory term. He defines it as "*a paradise of efficiency where defect and downtime, waste and waiting are long forgotten issues of a long forgotten age. In it, plant managers and CIOs scheme together in a seamless blend of data and production, of IT and manufacturing, to illuminate every turn of every machine, every cut of every blade, every move of every piece in its global dance to delivery."* In the article, the smart factory is viewed as the integration of three technologies: product lifecycle management (PLM), manufacturing execution systems (MES) and industrial automation. [65]

Finally, in the paper 'The Smart Factory: Exploring Adaptive and Flexible Manufacturing Solutions', authors make a more general definition of the concept that encloses the main characteristic of the definitions explained above. They define the smart factory as "*a manufacturing solution that provides such flexible and adaptive production processes that will solve problems arising on a production facility with dynamic and rapidly changing boundary conditions in a world of increasing complexity. This special solution could on the one hand be related to automation, understood as a combination of software, hardware and/or mechanics, which should lead to optimization of manufacturing resulting in reduction of unnecessary labour and waste of resource. On the other hand, it could be seen in a perspective of collaboration between different industrial and nonindustrial partners, where the smartness comes from forming a dynamic organization*".[66]

[64] Hadar, Bilberg (2012)
[65] http://www.industryweek.com/ [28-03-2014]
[66] Radziwon, et.al. (2014) p.1187

4.2 Technological enablers

As seen in the section before, there are different approaches of the smart factory concept, and different technologies are used in the definitions of each concept.

4.2.1 Ubiquitous computing

The concept of ubiquitous technology was introduced in the early 1980s by Mark Weiser, one of the pioneers in computer technology. It is known as the third wave in computing or the age of calm technology, when technology recedes into the background of our lives.[67] Weiser defines the ubiquitous computing as "*the physical world that is richly and invisibly interwoven with sensors, actuators, displays and computational elements, embedded seamlessly in the everyday objects of our lives, and connected through a continuous network*".[68]
The idea behind the concept is to make human life easier by embedding many kinds of pervasive and intelligent networked computers in objects and environments, making computing appear everywhere and anywhere, using any device, in any location, and in any format.[69] The creation of the Internet has marked a foremost milestone towards achieving ubiquitous computing vision which enables individual devices to communicate with any other device in the world.[70] Different technologies are used to implement the ubiquitous computing idea in the real world.

4.2.2 RFID Technology

Radio Frequency Identification (RFID) technologies are used to give the necessary information of the object itself. The non-contact and non-line-of-sight nature of the RFID technology, as well as the possibility of reading the RFID tags through a variety of visually challenging conditions are the main advantages of the use of this technology. [71] It is one of the numerous technologies grouped under the term of automatic identification (auto ID), a new way of controlling information and

[67] Zuehlke (2010) p. 129
[68] Weiser, et.al. (1999) p.694
[69] Yoon, et.al. (2014) p.2174
[70] Gubbi, et.al. (2013) p.1646
[71] Westkämper, Jendoubi (2003) p.3

material flow especially suitable for large production networks. Bar codes, magnetic inks and optical character recognition are other examples of auto ID technologies.[72] RFID systems can be used to identify, track, sort or detect a wide variety of objects. Their main role in the smart factory is to make possible the identification of the objects as well as their location.[73]

A RFID system basically consists of three hardware components:[74]

- An antenna, that emits radio signals to activate the tag and read and write the data on it
- A transceiver, which controls the system's data acquisition and communication
- A transponder, the tag itself that is programmed with unique information.

4.2.3 Wireless communication

Wireless technologies are used to enable the interaction between two or more points without the help of external infrastructure in a very cost efficient way. In the framework of smart factory, these technologies can be used for the connection of two or more devices as a communication system. Bluetooth, wireless LAN and Wi-Fi are some examples of technologies that are useful for this communication.[75]

4.3 The Smart Factory approach

In June 2005, a non-profit registered association named 'Technology Initiative SmartFactory' was established as a collaborative initiative of academic and industrial partners in Kaiserlautern, Germany. It was established in order to enable the entrance of these so-called 'smart' technologies in industry, and to transfer new technologies and concepts into industrial environments in a useful way. Their goal is also to create the foundation for the widespread use of these technologies in research and practice.[76]

---

[72] Wang (2014) p.2
[73] Wang (2014) p.2
[74] Westkämper, Jendoubi (2003) p.3
[75] Westkämper, Jendoubi (2003) p.3
[76] Zuehlke (2010) p.131

4.3.1 The idea

The demonstration plant of SmartFactory illustrates the vision of the factory of the future: diverse components of different manufacturers are connected with each other within it. Intelligent components are able to take over independently contextual tasks and to work self-sufficiently. In addition to that, the SmartFactory is modifiable and extendable in a user-defined way. Finally, major focus is put on the user-friendly configuration of the operating systems despite the fact of increasing complexity.[77]

4.3.2 The plant

The equipment basis for the SmartFactory is a hybrid production facility for the production of coloured liquid soap. The product is mixed, filled into dispenser bottles, individually labelled, and then delivered by customer order. The plant has been designed strictly modular and it consists as well of a process manufacturing part as of a piece goods handling part. The machinery and components are identical to those found in modern industrial plants and stem from various manufacturers so that the result is a multi-vendor production and handling facility available for research purposes, absolutely comparable in its complexity with real manufacturing plants.[78]

4.3.3 The partners

The association consists of 29 members from companies, enterprises and institutions of industry and research. The chemical company BASF, the worldwide leader in networking CISCO and a Business unit of Siemens-Division Industry Automation are some of the collaborators of the initiative. From the university field and apart from the driver of the initiative, the TU Kaiserslautern, the University of Lund and the ai2 Institute, one of the most important research organisations at the Universitat Politècnica de València, cooperate also with the association.[79]

[77] http://smartfactory.dfki.uni-kl.de/ [22-04-2014]
[78] Zuehlke (2010) p. 31-132
[79] http://smartfactory.dfki.uni-kl.de/ [22-04-2014]

5 Industry 4.0

A new type of production is about to turn the industrial world on its head. In fact, such is its potential impact that industry experts are already talking about the next industrial revolution, also called 'Industry 4.0'.[80]

The first industrial revolution was triggered by the invention of the steam engine and the mechanization of manual work in the 18th century. The second revolution involved the implementation of mass production techniques in the early 20th century, and the third was ushered in during the pas few decades by electronic systems and computes technologies for automating manufacturing processes.[81] Now a fundamental transition is taking place in the world of production. The real world and virtual reality continue to merge; modern information and communications technologies are being combined with traditional industrial processes, thereby changing the various areas of production.[82] (See figure 4)

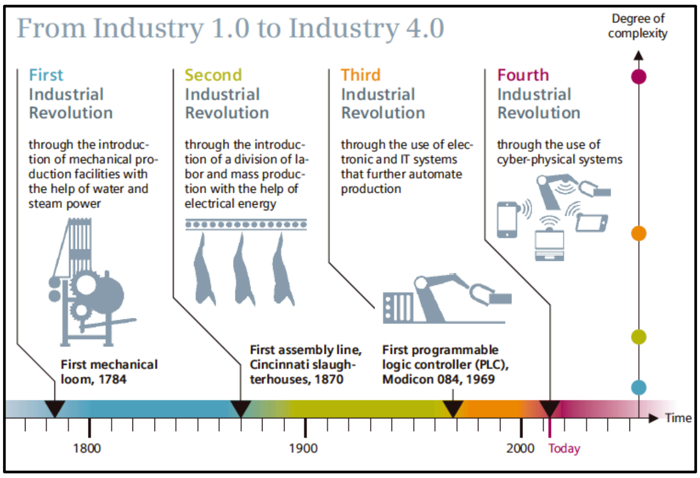

Figure 4: Evolution of production systems[83]

The aim of Industry 4.0 is to increase flexibility and productivity**.** As such, manufacturers will be able to produce customer-specific components fast, cost-effectively, and in small quantities – while automated processes will simultaneously ensure that individual component parts are re-ordered and that the order remains fully transparent within the company.[84]

[80] http://www.forbes.com/ [23-04-2014]
[81] http://www.siemens.com/ [20-05-2014]
[82] http://www.festo.com/ [20-05-2014]
[83] http://www.siemens.com/ [20-05-2014]
[84] http://www.forbes.com/ [23-04-2014]

The central aspects of the fourth industrial revolution can be further specified through three paradigms: the smart product, the smart machine and the augmented operator.[85]

- The basic idea of the smart product is to extend the role of the work piece to an active part of the system. To do that, products receive a memory on which the task and production requirements are stored. Therefore, the product itself is able to control its own production.
- The idea of the smart machine describes the process of machines becoming Cyber-Physical Systems (CPS). They represent automatic components with local control intelligence, which are able to communicate to other machines, production lines and products through open nets and semantic descriptions.
- The basic aspect of the augmented operator targets the support of the human in centre of a production plant through context-sensitive information provision and the enrichment of the real world with virtual information – Augmented Reality. As a result, the steadily rising technical complexity can be handled.

Using the Internet of things (IoT) and the cyber physical systems (CPS) as the basic technology, the goal of this revolution is the Smart Factory. The change sustains on the connection of the production with the network connectivity world via the IoT. “Smart production”, based on CPPS, becomes the norm in a world where intelligent IT-based machines, systems and networks are capable of independently exchanging and responding to information to manage industrial production processes.[86]

Industry 4.0 will involve the technical integration of CPS into manufacturing and logistics, and the use of the Internet of things in industrial processes. The IoT makes it possible to create networks incorporating the entire manufacturing process that convert factories into a smart environment. Cyber-Physical Production Systems compromise smart machines, warehousing systems and production facilities that have been developed digitally and feature end-to-end ICT-based integration.[87]

[85] http://smartfactory.dfki.uni-kl.de/ [23-04-2014]
[86] http://vint.sogeti.com/ [23-04-2014]
[87] Communication Promoters Group of the Industry-Science (2013) p.14

5.1 'Industrie 4.0': The German Initiative

Under the name 'Industrie 4.0', the German government created a strategic initiative to secure the future and competitiveness of German manufacturing industry.[88] This initiative is similar to the AMP (Advanced Manufacturing Partnership) developed in the United States. (See Section 6)

To do that, a Working group was created, which is composed by members from important industries of the country (such as ThyssenKrupp, Deutsche Telekom, Hewlett-Packard, Siemens and Bosch) and academic members of the most renowned German Universities (TU Darmstadt, Karlsruhe Institute of Technology, TU München and RWTH Aachen).[89]

The journey towards Industrie 4.0 will be an evolutionary process. Current basic technologies and experience will have to be adapted to the specific requirements of manufacturing engineering and innovative solutions for new locations and new markets will have to be explored. If this is done successfully, Industrie 4.0 will allow Germany to increase its global competitiveness and preserve its domestic manufacturing industry.[90]

5.1.1 Potential of the initiative

The implementation of the 'Industry 4.0' initiative in the German industry will enable many changes in the actual manufacturing system, improving it and solving some of the challenges facing the world today. What follows is a list of the high potential factors of the initiative: [91]

- Meeting individual customer requirements: The initiative allows individual, customer-specific criteria to be included in every operation phase, and enable last-minute changes to be incorporated.
- Flexibility: CPS-based ad hoc networking enables dynamics configuration of different aspects of business processes. This permits also more agile engineering processes, manufacturing processes can be changed, and huge increases in output can be achieved in short space of time.
- Optimised decision-taking: 'Industrie 4.0' provides end-to-end transparency

[88] Communication Promoters Group of the Industry-Science (2013) p.13
[89] Communication Promoters Group of the Industry-Science (2013) p.9
[90] Communication Promoters Group of the Industry-Science (2013) p.7
[91] Communication Promoters Group of the Industry-Science (2013) p.15-16

in real time, allowing early verification of design decisions in the sphere of engineering.

- Resource productivity and efficiency: CPS allows manufacturing processes to be optimised on a case-by-case basis across the entire value network. Moreover, production systems can be continuously optimised during production.
- Creating value opportunities through new services: The initiative open new ways of creating value and new forms of employment, specially there are opportunities for SMEs and startups to develop business-to-business services.
- Responding to demographic change in the workplace: 'Industrie 4.0' will enable diverse and flexible career paths that will allow people to keep working and remain productive for longer.
- Work-Life-Balance: The more flexible work organisation models of companies that uses CPS mean that they ate well places to meet the growing need of employees to strike better balance between personal development and continuing professional development.
- A high-wage economy that still is competitive: The strategy will allow Germany to develop its position as leading supplier and also become the leading market for Industry 4.0 solutions.

5.1.2 The Strategy

The implementation of 'Industrie 4.0' initiative in the German industry holds huge potential for manufacturing industry, as explained in the section above. In order to deliver the goals of creating a leading market among Germany's manufacturing companies and making Germany's manufacturing equipment industry into a leading supplier, this implementation should be based on a dual strategy.[92]

On the one hand, Germany's manufacturing equipment industry should seek to maintain its global market leadership by consistently integrating information and communication technology into its traditional high-tech strategies and at the same time, German industry can become the leading supplier of Smart manufacturing technologies. On the other hand, it will be necessary to create and serve new leading markets for CPS technologies and products. In order to deliver the goals of

[92] Communication Promoters Group of the Industry-Science (2013) p.29

this dual CPS strategy, the following features of 'Industrie 4.0' should be implemented:[93]

- Horizontal integration through value networks
- End-to-end digital integration of engineering across the entire value chain
- Vertical integration and networked manufacturing systems

5.1.3 Need for research

The journey towards Industrie 4.0 will require Germany to put a huge amount of effort into research and development. In order to implement the dual strategy, research is required into the horizontal and vertical integration of manufacturing systems and end-to-end integration of engineering. In addition, attention should be paid to the new social infrastructures in the workplace that will come about as a result of Industrie 4.0 systems, as well as the continued development of CPS technologies.[94]

If Industry 4.0 is to be successfully implemented, research and development activities will need to be accompanied by the appropriate industrial and industrial policy decisions. The Industrie 4.0 Working Group believes that action is needed in the following areas:[95]

- Standardisation and reference architecture: It is needed to set technical description of common standards due to the networking and integration of different companies that Industire 4.0 will involve
- Managing complex systems: Appropriate planning and explanatory models should be developed to manage the growing complexity of the manufacturing systems.
- A comprehensive broadband infrastructure for industry: Reliable and high-quality communication networks are key requirements for the initiative. Therefore, broadband Internet infrastructure needs to be expanded.
- Safety and security: It is important to ensure that production facilities and the products themselves do not pose a danger either to people or to the environment. Production facilities, products, and the data information they contain also need to be protected against bad use and unauthorised access.
- Work organisation and design: The role of employees, work content, work

[93] Communication Promoters Group of the Industry-Science (2013) p.6
[94] Communication Promoters Group of the Industry-Science (2013) p.6
[95] Communication Promoters Group of the Industry-Science (2013) p.6-7

processes and the working environment will change significantly in smart factories. Therefore, the implementation of a socio-technical approach to work organisation will offer workers the opportunity to enjoy grater responsibility and enhance their personal development.

- Training and continuing professional development: It will be necessary to implement appropriate training strategies to organise work in a way that promotes learning. Therefore, model projects and “best practices networks” should be promoted and learning techniques should be investigated.
- Regulatory framework: Existing legislation will need to be adapted to take account of new innovations. The challenges include the protection of corporate data, liability issues, handling of personal data and trade restrictions.
- Resource efficiency: ‘Industrie 4.0’ will deliver gain in resource productivity and efficiency. It will be necessary to calculate the trade-offs between the additional resources that will need to be invested in smart factories and the potential savings generated.

6 Advanced Manufacturing Partnership (AMP)

Advanced manufacturing is a family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or (b) make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology. It involves both new ways to manufacture existing products, ant the manufacture of new products emerging from new advances technologies[96].

Advanced Manufacturing Partnership was created in 2011 by the American President to maintain American leadership in manufacturing. Due to the high global competitors such as China, Japan, Germany and South Korea, the U.S. has lost his position as the world's largest manufacturer, which remained for more than a century.

The aim of AMP is to revitalize and re-invent the manufacturing sector with the collaboration between industry, academia, and government and reposition the U.S. to lead the world in new disruptive advanced technologies that are changing the face of manufacturing. In this way, accelerating the advanced manufacturing will require the cooperation of communities, educators, workers, and business, as well as Federal, State, and local governments.

The revitalization of the American manufacturing industry provides the opportunity for high-quality and good-paying jobs for American workers. Moreover, a strong manufacturing sector that develops and adapts to new technologies is vital to ensure ongoing U.S. leadership in innovation and manufacturing capabilities using advanced technologies and techniques are vital to national security.[97]

6.1 Background of the initiative

During more than a century, the United States has been the world's leader producer of manufactured goods. Manufacturing has also served as an engine for innovation and knowledge production, and is also in the support of the national and homeland security. Although this historic strength, American leadership and competitiveness

[96] President's council of advisors on Science and technology (2011) p. ii
[97] President's council of advisors on Science and technology (2011) p.9

in manufacturing are at risk, and since the early 2000, manufacturing production and manufacturing employment has declined in the U.S.[98]

The loss of the manufacturing leadership is not only in low-tech industries and products and not just due to low-wages abroad. The U.S. is also losing ground in the production of high-tech products (See Figure 5), including those resulting from U.S. innovation and inventions, and in manufacturing-associated R&D. As manufacturing declines in America, other countries are investing heavily in advancing their manufacturing leadership, innovation systems, and R&D[99].

With the AMP initiative it is expected to bring the American manufacturing industry back to the leadership position they had during the 20th century.

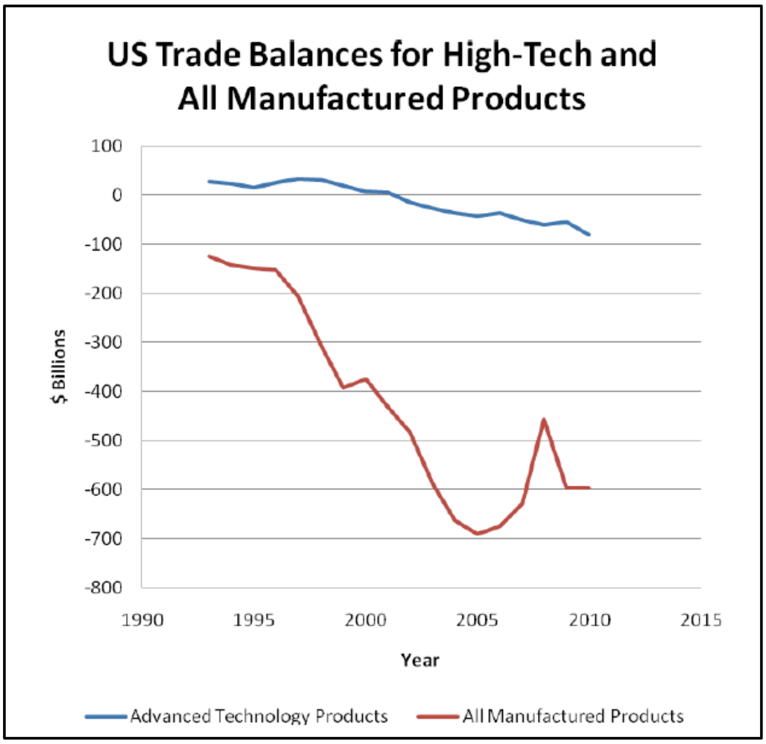

Figure 5: Graphic of US Trade Balance for High-Tech and All Manufactured Products [100]

[98] President's council of advisors on Science and technology (2011) p.5-7
[99] President's council of advisors on Science and technology (2011) p.5-7
[100] President's council of advisors on Science and technology (2011) p.4

6.2 Recommendations of the AMP Steering Committee

In order to identify the most pressing challenges and transformative opportunities to improve the technologies, processes and products in manufacturing industries, a Steering Committee was created. It is made up of the Presidents of the top engineering universities (MIT, UC Berkeley, Stanford, CMU, Michigan and Git), and the CEOs of leading US enterprises (including Caterpillar, Corning, Dow Chemical, Ford, Honeywell, Intel, Johnson & Johnson, Northrop Grumman, Procter & Gamble, and United Technologies).[101]

The committee was founded in 2012 and chaired first by Susan Hockfield (MIT President until 2012) and Andrew Liveris (President, chairman and CEO of the Dow Chemical Company), and later by this second and Rafael Reif (New MIT President).[102] In the document 'Report to the President on capturing domestic competitive advantage in advanced manufacturing', the AMP Steering Committee developed a set of recommendations built around three pillars: enabling innovation, securing the talent pipeline, and improving the business climate. Next are detailed these recommendations according to the pillar that are based on.[103]

PILLAR I: ENABLING INNOVATION

1. Establish a National Advanced Manufacturing Strategy: Through a systematic process to identify and prioritize cross-cutting technologies, a national advanced manufacturing strategy should be developed and maintained.
2. Increase R&D Funding in Top Cross-Cutting Technologies: In addition to identifying a 'starter list' of cross-cutting technologies that is vital to advanced manufacturing, the AMP Steering Committee has laid out a process of evaluating technologies for R&D funding.
3. Establish a National Network of Manufacturing Innovation Institutes: Manufacturing Innovation Institutes (IMIs) should be formed as public-private partnerships to foster regional ecosystems in advanced manufacturing technologies. These MIIs are one vehicle to integrate many recommendations.

---

[101] Communication Promoters Group of the Industry-Science (2013) p.70
[102] http://www.manufacturing.gov/ [13-05-2014]
[103] President's council of advisors on Science and Technology (2012) p.11

4. Empower Enhanced Industry/University collaboration in Advanced Manufacturing Research: The treatment of tax-free bound-funded facilities at universities should be changed in order to enable grater and stronger interactions between universities and industry.
5. Foster a More Robust Environment for Commercialization of Advanced Manufacturing Technologies: The AMP Steering Committee recommends actions to connect manufacturers to university innovation ecosystems and create a continuum of capital access from start up to scale up.
6. Establish a National Advanced Manufacturing Portal: A searchable database of manufacturing resources should be created to serve as a key mechanism to support access by small and medium-sized enterprises to enabling infrastructure.

PILLAR II: SECURING TALENT PIPELINE

7. Correct Public Misconceptions About Manufacturing: Building excitement and interest in career in manufacturing is a critical national need, and an advertising campaign should be undertaken as one important step in this direction.
8. Tap the Talent Pool of Returning Veteran: Returning veterans possess many of the key skills needed to fill the skills gap in the manufacturing talent pipeline. The AMP Steering Committee makes specific recommendations on how to connect these veterans with manufacturing employment opportunities.
9. Invest in Community College Level Education: The community college level of education is the ‘sweet spot’ for impact on the skills gap in manufacturing. Investment in this sector should be increased, following the best practices of some of the leading innovators in this space.
10. Develop Partnership to Provide Skills Certifications and Accreditation: Probability and modularity of the credentialing process in advanced manufacturing would allow coordinated action organizations that feed the talent pipeline.
11. Enhance Advanced Manufacturing University Programs: Universities should bring new focus to advanced manufacturing through the development of educational modules and courses.

12. Launch National Manufacturing Fellowships & Internships: The creation of national fellowships and internships in advanced manufacturing is recommended to bring needed resources but more importantly national recognition to manufacturing career opportunities.

PILLAR III: IMPROVING THE BUSINESS CLIMATE

13. Enact Tax Reform: A set of specific tax reforms should be enacted that 'level the playing field' for domestic manufacturers.
14. Streamline Regulatory Policy: A framework for smarter regulations should be created for advanced manufacturing.
15. Improve Trade Policy: Specific trade policy proposals are advanced to improve the business climate.
16. Update Energy Policy: Energy issues of importance in manufacturing must be addressed.

6.3 Advanced Manufacturing National Program Office (AMNPO)

The Advanced Manufacturing National Program Office (AMNPO) – hosted by the National Institute of Standards and Technology (NIST), Department of Commerce – coordinates all federal agencies involved in the AMP: Department of Commerce, Defence, Education and Energy, the National Science Foundation, and NASA. The current director of the AMNPO is Michael F. Molnar, Chief Manufacturing Officer of NIST.[104]

The office is charged with convening and enabling the collaboration between industry, companies and private-public partnerships focused on manufacturing innovation and engaging U.S. universities, as well as designing and implementing an integrated whole of government advanced manufacturing initiative to facilitate collaboration and information sharing across federal agencies.[105]

This coordination will enhance technology transfer in U.S. manufacturing industries and help companies overcome technical obstacles to scaling up production of new technologies. It will also enable more effective collaboration in identifying and

[104] Executive Office of the President, National Science and Techonolgy Council, AMNPO (2013) p.4
[105] http://www.manufacturing.gov/ [30-04-2014]

addressing challenges and opportunities that reach technology areas and cut across agency missions. In addition, the office will link federal efforts to the growing number of private-sector partnerships between manufacturers, universities, state and local governments, and other organizations.[106]

6.4 National Network for Manufacturing Innovation (NNMI) and Institutes for Manufacturing Innovation (IMIs)

The National Network for Manufacturing Innovation (NNMI) was created following the recommendation of the Steering Committee. The Federal investment in the NNMI serves to create an effective manufacturing research infrastructure for U.S. industry and academia to solve industry relevant problems. The NNMI will fill a gap in the innovative infrastructure, allowing new manufacturing processes and technologies to progress fluently from basic research to implementation in manufacturing.[107]

The NNMI consists of linked Institutes for Manufacturing Innovation (IMIs) with common goals, but unique concentrations. The IMIs will bring together industry, universities and community colleges, Federal agencies, States, and localities to accelerate manufacturing innovation and scale up by investing in industrially-relevant, cross-cutting product and process technologies. [108]

The investment made by the president for the creation of the National Network for Manufacturing Innovation will be managed collectively by the federal agencies that are part of the AMNPO.[109] Crowd Sourcing the Design of the NNMI

Beginning in April 2012, a broad public engagement strategy by the AMNPO was used to ‘crowd source’ the NNMI program design. The AMNPO started a strategy to solicit input form industry, academia, State and regional governments, economic

[106] http://www.manufacturing.gov/ [30-04-2014]
[107] Executive Office of the President, National Science and Techonolgy Council, AMNPO (2013) p.4
[108] Executive Office of the President, National Science and Techonolgy Council, AMNPO (2013) p.4
[109] Executive Office of the President, National Science and Techonolgy Council, AMNPO (2013) p.2

development authorities, industry associations and consortia, private citizens, and other interested parties.[110]

The AMNPO organized a Request for Information (RFI) and series of regional workshops to get inputs for the NNMI design. In total they received 78 separate RFI responses representing the viewpoints of nearly more than 100 separate entities.[111]

In the academic field, some of the most important universities of America participated in the NNMI Public Workshop and RFI. For instance, the Columbia University, the College of Engineering of the University of California in Berkeley and students from the Massachusetts Institute of Technology are examples of the 282 academic people and institutions that were part of it. From the Industry, important companies such us the multinational Procter and Gamble, the chemical DuPont or the Eastman Kodak took part in the workshop and RFI. A total of 264 employees and companies participated in these events. People from Economic and Development Organizations, from the Federal and State Government and from Research Areas and Non-Profit Organizations were also participants of these activities.[112]

6.4.1 Focus and Activities of the IMIs

Each institute will have a unique and well-defined focus area dedicated to integrate capabilities through collaborations addressing cross-cutting manufacturing challenges, yielding solutions that have the potential to retain or expand industrial production in the U.S. Some examples of the areas on which the IMIs can be based on are manufacturing process, enabling technology, manufacturing processes for new advanced materials, or an industry sector.[113]

The proposing teams, which will be driven by the needs of the industry and the AMNPO partners, and the opportunities created by the new technologies, will

[110] Executive Office of the President, National Science and Techonolgy Council, AMNPO (2013) p.22
[111] Executive Office of the President, National Science and Techonolgy Council, AMNPO (2013) p.iii
[112] Executive Office of the President, National Science and Techonolgy Council, AMNPO (2013) p.27-41
[113] Executive Office of the President, National Science and Techonolgy Council, AMNPO (2013) p.5

define the focus area of each institute and AMNPO partners will evaluate its efficacy. [114]

The activities developed in the IMIs will be addressed basically to the research, academic and industrial field. These activities will include applied research, development, and demonstration projects that reduce the costs and risk of developing and implementing new technologies in advanced manufacturing; educational and training at all levels; development of innovative methodologies and practices for increasing the capabilities and capacity of supply chain expansion and integration; engagement with SMEs; and shared facilities infrastructures to local especially SMEs and start-ups. [115]

6.4.2 IMIs

6.4.2.1 AMERICA MAKES: the Pilot Institute [116]

America Makes was created in 2012 as a pilot Institute to jumpstart the NNMI initiative. When it was started, the Institute was called National Additive Manufacturing Innovation Institute (NAMII) and it was later rebranded as America Makes. It is headquartered in Ohio and driven by the National Centre of Defence Manufacturing and Machining (NCDMM).

America Makes focuses on helping the U.S. grow capabilities and strength in additive manufacturing by facilitating collaboration among leaders from business, academia, non-profit organizations and government agencies. They aim to make 3D printing industry more globally competitive while focusing on areas different areas such as design, materials and workforce.

- THE TECHNOLOGY: 3D printing

    The topic of Additive Manufacturing, commonly known as 3D printing, was chosen as the focus of the Pilot Institute due to its benefit for the defence, energy, space, and commercial sectors of the nation.

    The 3D printing technology is an emerging and evolving collection of manufacturing processes that build metal, plastic, or ceramic parts by adding

[114] Executive Office of the President, National Science and Techonolgy Council, AMNPO (2013) p.5
[115] Executive Office of the President, National Science and Techonolgy Council, AMNPO (2013) p.7
[116] Executive Office of the President, National Science and Techonolgy Council, AMNPO (2013) p.21

material in successive layers, precisely placing material as directed, based on a software representation of the three-dimensional part geometry.

- PARTNERS

America Makes includes more than 80 companies, 9 research universities, 6 community colleges, and 18 non-profit institutions. What follows is a list of the most relevant partners in the academic and industrial field.

Companies:

- Boeing: world's largest aerospace company that designs, manufactures and sells fixed-wing aircraft, rotorcraft, rockets and satellites.
- 3D Systems Corporation: Integrated solutions 3D printing company specialized in 3D printers, print materials, professional and 3D imaging and customization software.
- Lockheed Martin: American global aerospace, defence, security and advanced technology company.
- Northrop Grumman: Global security company providing innovative systems, products and solutions in unmanned systems, cyber, C4ISR, and logistics and modernization to government and commercial customers.
- Stratasys: Manufacturer of 3D printers and 3D production systems for office-based rapid propotyping and direct digital manufacturing solutions.
- Oxford Performance Materials: Company specialized in 3D printing of biomedical devices and biomedical raw materials.
- Wholers Associates: Consulting firm that provides technical and strategic advice on the 3D printing and rapid product development.

Universities

- Carnegie Mellon University
- Case Western Reserve University
- Kant State University
- Lehigh University
- Penn State University
- Robert Morris University
- University of Akron
- University of Pittsburgh
- Youngstown State University

6.4.2.2 Next Generation Power Electronics National Manufacturing Innovative Institute[117]

A North Carolina-headquartered consortium of businesses and universities, guided by North Carolina State University, was selected to lead a manufacturing innovation institute for the next generation of power electronics. It is supported by the Department of Energy and has the contribution from industry and other partners.
This institute will help to invent, design and manufacture new semiconductor chips and devices by providing companies shared facilities, equipment, and testing and modelling capabilities from the power electronics supply chain. It will also pair chip designers and manufacturers with large power electronic manufacturers and suppliers in order to bring power electronics faster to the market. Finally, the institute will also offer training, higher education programs and internships to American workers to give them the skills for new job opportunities and meet the needs of this emerging and competitive industry.

- THE TECHNOLOGY: wide bandgap semiconductors (WBG)

  The focus of the Institute is to make possible the next generation of energy-efficient, high-power electronic chips and devices that will make power electronic devices faster, small and more efficient. To do that, they aim to make the wide bandgap (WBG) semiconductor technologies cost-competitive with current silicon-based power electronics.
  WBG semiconductors have bandgaps significantly greater than those of silicon semiconductors. This way, fewer electrons will excite when electrical current is applied to WBG semiconductors, enabling superior current control and reducing energy losses. These semiconductors can operate at higher voltages, higher frequencies and higher temperatures than the silicon based components. This makes the power electronic modules more powerful and energy efficient.[118]
- PARTNERS

  Companies
  - ABB: Global leader in power and automation technologies.
  - Deere & company: One of the largest manufacturers of agricultural machinery in the world.

[117] http://www.manufacturing.gov/ [14-05-2014]
[118] http://energy.gov/ [14-05-2014]

- Delphi Automotive LLP: Manufacturer and marketer of vehicle components. It offers electrical and electronics, safety and thermal technology solutions to the automotive and commercial vehicle market.
- Toshiba International Corporation: Multinational engineering and electronics company.

Universities
- North Carolina State University
- Arizona State University
- University of California, Santa Barbara
- Virginia Polytechnic and State University

6.4.2.3 Digital Manufacturing & Design Innovation (DMDI) Institute

On Februray 2014, President Obama announced the selection of an Illinois consortium led by UI Labs to lead the DMDI Institute. This Institute, which will be overseen by the Department of Defence, is still on the first stages of development.[119]

The DMDI Institute will be a public-private partnership that will be focused on the development and implementation of the 'digital thread' in the U.S. industry, the so-called factory of the future. The application of the 'digital thread', that integrates and drives modern design, manufacturing and product support processes, will help to reduce cycle time and to drive down the time and cost to take products from concept to production. It is also a way to deal with constantly increasing complexity in products and manufacturing enterprises.[120]

The DMDI Institute will provide the proving ground to link promising information technologies, tools, standards, models, sensors, controls, practices and skills, and then apply these capabilities to the industry. The Institute will be the core to help U.S. manufacturers improve at connecting their flexible manufacturing operations, driving them securely with digital data, controlling quality feedback from sensors and data analysis, and delivering products in significantly less time than global competitors.[121]

[119] http://www.manufacturing.gov/ [14-05-2014]
[120] http://www.manufacturing.gov/ [14-05-2014]
[121] http://www.manufacturing.gov/ [14-05-2014]

- TECHNOLOGIES

  The specific technology advancements related to the intelligent electro-mechanical design & manufacturing that will be the focus of the institute are:[122]

  - Advanced Manufacturing Enterprise: This includes agile and robust manufacturing strategies and integrated capabilities that reduce the cost and time of producing complex systems and parts by the development and implementation of modelling and simulation tools. It also includes a focus on tools and practices to minimize multiple design and prototypes, all connected via the 'digital thread' to enable collaboration between all the participants in the product development.
  - Intelligent Machines: This involves the development and integration of smart sensors, controls, and measurement, analysis, decision and communication software tools for providing continuous improvement and sustainability.
  - Advanced Analysis: This is based on advances in high-performance computing that includes developing and integrating smart design tools to help reduce manufacturing cost.
  - Cyber Physical Systems Security: These are methods and technologies to address the new vulnerabilities of cyber physical systems in intelligent machines, sensors and control systems, in order to provide a secure and trusted infrastructure for the management of information assets in a highly collaborative manufacturing environment.

6.4.2.4 Lightweight and Modern Metals Manufacturing Innovation (LM3I) Institute

The LM3I is leaded by a selection of a Michigan headquartered consortium of businesses and universities, led by EWI. The announcement of the leading team was made on February 2014 because of that, the institute is still developing its principles. Due to its importance in the defence field, the Institute is supported by the Department of Defence.[123]

The focus of the Institute will be on the integrated design and manufacturing of lightweight components and structures fro commercial and defence applications, and the verification of those designs through pilot production and validation

[122] http://www.manufacturing.gov/ [15-05-2014]
[123] http://www.manufacturing.gov/ [15-05-2014]

through experimental testing. The institute will work in collaboration with industry, academia and government in rapidly maturing and demonstrating production scale-up of existing, innovative, lightweight alloys, as well as shortening the time to design and integrate these alloys and third generation steels into new products. The Institute will also develop more affordable, competitive and automated manufacturing processes, and the tools, skills and knowledge base to use and Integrated Computational Materials Engineering (ICME) infrastructure efficiently and effectively.[124]

The LM3I institute will make the U.S. more competitive by scaling-up research to accelerate market expansion for products such as wind turbines, medical devices, engines, armoured combat vehicles, and airframes, and lead to significant reductions in manufacturing and energy costs.[125]

- THE TECHNOLOGY: Lightweight metals

  Advanced lightweight metals possess mechanical and electrical properties comparable to traditional materials while enabling much lighter components and products. The availability of advanced lightweight metals is a pervasive factor in improving the performance of many systems in defence, energy, transportation and general engineered products, each representing large sectors of the U.S. economy. Moreover, lightweight metals have additional applications in areas such as wind turbines, medical technology, pressure vessels and alternative energy sources.[126]

[124] http://www.manufacturing.gov/ [15-05-2014]
[125] http://www.whitehouse.gov/ [15-05-2014]
[126] http://www.manufacturing.gov/ [15-05-2014]

7 Production Ramp-Up

Production ramp-up is '*The period between the end of product development and full capacity production*' which manufacturing enterprises experience.[127] In other words, it is the process of bringing a production system up to its required operational characteristics after it has been designed and build and before it is taken into full operation. In figure 6, ramp-up is shown in the context of the manufacturing system development and production phases.[128]

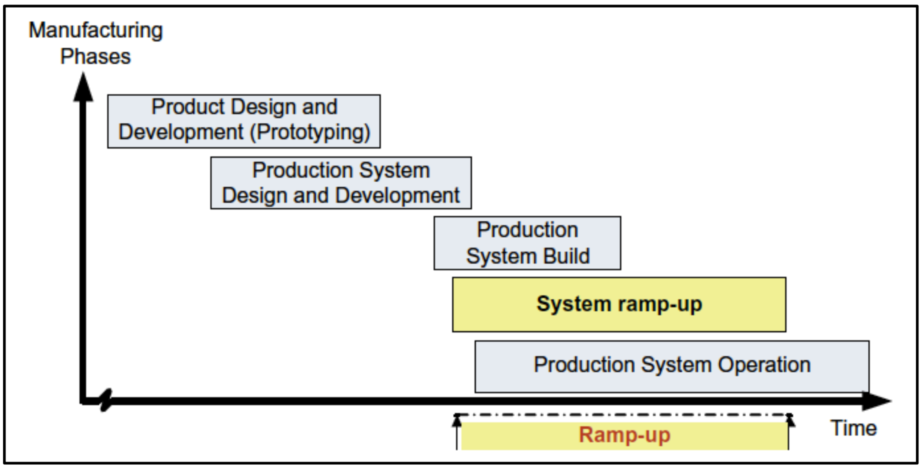

Figure 6: Ramp-up phase in the manufacturing time line[129]

This phase is characterized by high demand and low production rates which drives to low yields for the enterprise. The company finds itself pressured from these two sides, an effect referred to as the 'nut-cracker'. High demand emerges due to the 'freshness' and even 'newness' of the product during this phase. Thus, customers are ready to pay a premium price for it. Production process is still poorly understood and, inevitably, much of what is produced does not work properly the first time. Due to this lack of knowledge of the production process, learning and making right decisions during this period is crucial to reduce the time-to-market of new products.[130]

Since each ramp-up is unique concerning the product, the process, the technology, the circumstances and the coaction of these four factors, the knowledge of the ramp-up situation and the current ramp-up capability of the enterprise are

[127] Terwiesch, Bohn (2001) p.1
[128] Doltsinis, Ratchev, Lohse (2013) p.85
[129] Doltsinis, Ratchev, Lohse (2013) p.86
[130] Terwiesch, Bohn (2001) p.1

fundamental requirements for the subsequent improvement of the ramp-up capability of the production system.[131]

The main goal during production ramp-up is to manage progress as rapidly as possible, achieving the required production volume to enter the market, and maximise the likely profit.[132]

7.1 Assessing and Improving Ramp-Up Capability

Researchers of the Leibniz University of Hanover have developed a project called 'RampAble – Configuration of Ramp-up-viable Production Systems', which aims to provide small and medium-sized enterprises (SME) with a software-tool that allows them to assess and improve the ramp-up capability of their production systems. They developed a methodology as a basis for this software-tool, which connects certain objects using different handling methods.[133]

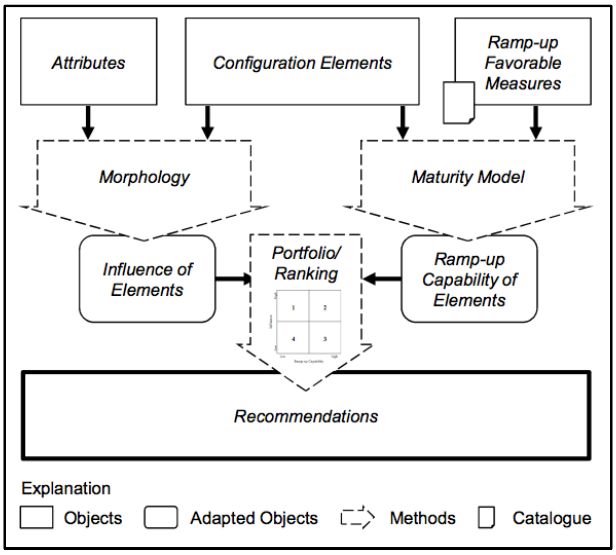

Figure 7: Functionality of the Methodology[134]

Figure 7 shows the connection of the four objects of the methodology (attributes, ramp-up-favourable measures, configuration elements and recommendations) by three methods (morphology, maturity models and portfolio).[135]

[131] Tschöpe, Knüppel, Nyhuis (2013) p.796
[132] Doltsinis, Ratchev, Lohse (2013) p.85
[133] Tschöpe, Knüppel, Nyhuis (2013) p.796
[134] Tschöpe, Knüppel, Nyhuis (2013) p.796
[135] Tschöpe, Knüppel, Nyhuis (2013) p.796

7.1.1 Objects of the methodology[136]

- ATTRIBUTES (Input): focus on the identification and description of product changes and the company's situation during ramp-ups. The 8 attributes identified to describe the ramp-up situation in an exact way are:
    - Complexity of product
    - Complexity of technology
    - Complexity of process
    - Variants
    - Suppliers
    - Personnel
    - Degree of automation
    - Environment
- CONFIGURATION ELEMENTS (Input): from all the elements of a production systems obtained by opposing the levels of production system to the configuration fields, the 18 with the highest influence on the configuration of ramp-up capable production systems were identified as configuration elements.

  Production system:
    - Network
    - Site
    - Factory
    - System
    - Workstation

  Configuration fields
    - Technology
    - Logistics
    - Organization
    - Personnel
- RAMP-UP FAVOURABLE MEASURES (Input): the combination of ramp-up enablers and configuration elements allows the allocation of each ramp-up favourable measure. In total 72 fields that define each ramp-up favourable

[136] Tschöpe, Knüppel, Nyhuis (2013) p.797

measure by the combination of a ramp-up enabler and a configuration element, are defined in a catalogue.

Ramp-up enablers:

- Convertibility
- Reactivity
- Availability
- Transparency

- RECOMMENDATIONS (Final Output): measures with the highest potential to improve the ramp-up capability of a production system concerning a specific situation. Recommendations are directly allocated to the highest potential configuration elements.

7.1.2 Methods of the methodology[137]

- MORPHOLOGY: influence of the *configuration elements*.
  Describe a certain situation by identifying the different influences of the 18 *configuration elements* on the ramp-up situation by systematically comparing ramp-up characteristic attributes.

- MATURITY MODEL: ramp-up capability of each *configuration element*.
  Provides the possibility of assessing the capability of a production system. The maturity model uses the *ramp-up favourable measures* to describe the current ramp-up capability of each of the *configuration elements*. This capability is defined by the relevance and the execution status of the *ramp-up favourable measures* allocated to this element.

- PORTFOLIO: connexion of the morphology and maturity model results.
  It opposes the influence of the *configuration element* to their ramp-up capability. The Portfolio is divided into 4 quadrants and each configuration element is located in one of these quadrants in order to derive *recommendations*:

  (1) Raw diamantes: High influence to the ramp-up situation and ramp-up capability low. These elements should be focused and their allocated measures should be realized.

[137] Tschöpe, Knüppel, Nyhuis (2013) p.797-799

(2) Gold: High influence to the ramp-up situation and also high ramp-up capability. These elements facilitate the ramp-up and therefore need to be controlled.
(3) Silver: Low influence on the ramp-up situation and high ramp-up capability. They do not have to be focused nor improved due to its low potential for the ramp-up.
(4) Bronze: Low influence on the ramp-up situation and low capability. They do not have to be focused, only be improved.

7.1.3 **Functioning of the methodology and software tool**[138]

Three basic steps should be followed when using the software-tool:

1. Characterization of the ramp-up situation: specify the eight attributes the morphology of each attribute.
2. Identification of the current ramp-up capability: identify the relevance and the execution status for each of the measures.

The software-tool generates a portfolio

3. Improvement of the ramp-up capability of the production system: the portfolio displays the different potential of the configuration elements. The elements with high potential can be focused and measures with high influence can be taken.

7.2 Design of the Ramp-up phase when implementing a new location

When implementing a new location, three factors are crucial to determine its success. First, it is important to plan the new location carefully and systematically, companies should not undertake too much at once when establishing new locations, building up more complexity than they can control. The second important factor is to build an excellent HR management at the new location in order to provide suitable personnel at low cost. Finally, it is important to design an optimal

[138] Tschöpe, Knüppel, Nyhuis (2013) p.799

ramp-up phase. This section is focused on the strategies needed to carry out this last factor.[139]

7.2.1 Optimal design of the ramp-up phase

Ramp-up strategies[140]

Production downtimes, ramp-up delays and loss of production because of deviations from plan.

- Causes of deviations from plan: inside (deficits in the skills of machine operators or mechanics, design changes at short notice, problems in coordinating lines) or outside (problems with the quality of materials or delays in the supply chain) the company.
- Solution for deviations from plan: sequential introduction and manufacturing steps. Complexity management.

  RAMP-UP VARIANTS

  Mode 1: sequential introduction of the product range and simultaneous launch of manufacturing steps. Mass products and production lines with long setup times.

  Mode 2: simultaneous launch of product range and of manufacturing steps. Products and manufacturing processes are simple or staff are extremely skilled and highly trained.

  Mode 3: sequential launch of product range and of manufacturing steps. Products and processes are very demanding. Long ramp-up curves, economies of scale are not realized until a late stage. TYPES: introducing processes product by product or process by process.

  Mode 4: simultaneous launch of product range and sequential launch of manufacturing steps. Diverse, complex manufacturing processes with high quality requirements.

[139] Simon, et.al. (2008) p.237-261

[140] Simon, et.al. (2008) p.261-265

Equipment transfer vs. purchase (One of the main decisions affecting costs)[141]

STANDARD MACHINERY: more efficient to transfer equipment that is no longer needed than to sell it and buy new equipment at the new location.

- Key factors for efficient transfer: planning the optimal export and import sequence, overhauling the machine procuring suitable packaging/special hosting equipment, monitoring reassembly by experienced staff.
- Customer audits
- Transfer of machinery currently in use: plan additional capacity to bridge the loss

[141] Simon et.al. (2008) p.261-265

8 Connection between concepts

In Cyber-Physical Systems (CPS), objects and processes of the physical world are integrated with the virtual world of global digital networks, such as the Internet, leading to an Internet of things, data and services. One example of CPS is an intelligent manufacturing line, where the machine can perform many work processes by communicating with the components.[142]

In other words, Cyber-Physical Systems and the Internet of Things are the basic technologies that are permitting the consolidation of what is called Smart Factory, the next generation of manufacturing systems. Such is the potential of these emerging technologies that governments of different countries are building up initiatives to motivate the development and implementation of these and other future technologies. This is in short, the main relation given between the concepts that this paper is based on.

As just mentioned, CPS play an important role in the Smart Factory approach. To develop its function CPS may be equipped with intelligent sensors and actors, which allow them to interact with the environment. This enables CPS on the one hand to adopt its behaviour to the environment and on the other hand to learn new ways of reaction – and even the strategy to optimize this. These 'smart' abilities belong to machines but also to products and modules – even in the phase of early development. This means that these smart products can control the whole production system in an early phase of development and can interact between machine and user.[143]

The relation between the Internet of things and the smart factory is quite obvious. In section 4.1 different visions of the smart factory concept are given, and the Internet of things is the basic technology in some of these definitions, either directly or behind the ubiquitous computing idea, closely linked to this concept.

But the potential of CPS and IoT is not only useful for applications in the production and management field, and their connexion goes beyond manufacturing systems. As mentioned in the sections above, the implementation of these technologies has many other uses and sometimes both are needed for a concrete application.

[142] http://www.eitictlabs.eu/ [24-05-2014]
[143] Würtz, Kölmel (2012) p.495

Examples are their utilization for health-care and energy conservation purpose, among others.

More in general, IoT is to extend the Internet to connect physical objects through sensors, bringing together many appliances and supporting control of these appliances to make environmental data much more available. CPS is to extend embedded systems to include physical objects into computing systems, linking many physical sensor data to detailed simulation models running on large data centres. Thus, both terms empirically represent aspirations of developing the future interconnection environment. New techniques and methods developed through research and application will help to develop this future interconnection environment.[144]

[144] Zhuge (2014) p.184 / Pu (2011) p.229

List of References

ATZORI L., IERA A., MORABITO G., 2010: The Internet of Things: A survey*, in: Computer Networks*, Vol. 54, p.2787-2805, Italy

BAHETI R., GILL H., 2011: Cyber-Physical Systems, *in: The impact of Control Technology*, p.161-166, available in: http://ieeecss.org/main/IoCT-report

BRAZELL J.B., 2014: The Need for a Transdisciplinary Approach to Security of Cyber Physical Infrastructure*, in: Applied Cyber-Physical Systems,* Chapter 3, p.15-32, Springer, New York

BORY M., SCHMIDT A., 2014: Challenges in Engineering Cyber-Physical Systems*, in: IEE Computer Society*, Vol. 47, Issue 2, p.70-72, Germany

COMMUNICATION PROMOTERS GROUP OF THE INDUSTRY-SCIENCE RESEARCH ALLIANCE, 2013: Securing the future of German manufacturing industry: Recommendations for implementing the strategic initiative INDUSTRIE 4.0, Germany

DERLER P., LEE E.A., SANGIOVANNI-VINCENTELLI A., 2011: Modeling Cyber-Physical Systems, *in: Proceedings of the IEEE,* Vol. 100, Issue 1, p.13-28, Berkeley, USA

DOLTSINIS S.C., RATCHEV S., LOHSE N., 2013: A framework for performance during production ramp-up of assembly stations, *in: European Journal of Operational Research,* Vol. 229, p.85-94, Nottingham, United Kingdom

EXECUTIVE OFFICE OF THE PRESIDENT, NATIONAL SCIENCE AND TECHNOLOGY COUNCIL, ADVANCED MANUFACTURING NATIONAL PROGRAM OFFICE, 2013: National network for manufacturing innovation: A preliminary design, Washington

FLEISCH E., SARMA S., THIESSE F., 2009: Preface to the focus theme section: ‘Internet of things’, *in: Electronic Markets*, Vol. 19, Issue 2-3, p.99-102, St Gallen, Switzerland

GUBBI J., et.al., 2013: Internet of things (IoT): A vision, architectural elements and future directions, *in: Future Generation Computer System*, Vol. 29, p.1645-1660, Melbourne, Australia

HADAR R., BILBERG A., 2012: Glocalized Manufacturing – Local Supply Chains on a Global Scale and Changeable Technologies, *in: Flexible Automation and Intelligent Manufacturing, FAIM2012,* Denmark

KRAMP T., KRANENBURG R., LANGE S., 2013: Introduction to the Internet of Things, *in: Enabling things to talk,* Chapter 1, p.1-12

LEE E.A., 2008: Cyber Physical Systems: Design Challenges, *in: 11th IEEE International Symposium on Object Oriented Real-Tome Distributed Computing (ISORC),* p.363-369, Berkeley, USA

LUCKE D., CONSTANTINESCU C., WESTKÄMPER E., 2008: Smart factory – A step towards the next generation of manufacturing, *in: Manufacturing Systems and Technologies for the New Frontier,* p.115-118, Springer

MIORANDI D., et.al., 2012: Internet of things: Vision, applications and research challenges*, in: Ad Hoc Networks*, Vol. 10, p.1497-1516, Italy

PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY, 2011: Report to the president on ensuring American leadership in advanced manufacturing, Washington

PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY, 2012: Report to the president on capturing domestic competitive advantage in advanced manufacturing, Washington

PU C., 2011: A world of opportunities: CPS, IoT, and Beyond, *in: Proceedings of the Fifth ACM International Conference on Distributed Event-Based Systems*, New York, USA

RADZIWON A., et. al., 2014: The Smart Factory: Exploring Adaptive and Flexible Manufacturing*, in: Procedia Engineering*, Vol. 64, p.1184-1190, Denmark

RAJKUMAR R., et.al., 2010: Cyber-Physical Systems: The Next Computing Revolution, *in: Design Automation Conference (DAC), 47th ACM/IEEE,* p.731-736, Anaheim, USA

SIMON S., et.al., 2008: Implementation: Ramping Up New Facilities for Top Performance, *in: Global Production. A Handbook for strategy and Implementation*, Chapter 6, p.236-269, Springer

TANIK U.J., BEGLEY A., 2014: An Adaptive Cyber-Physical System Framework for Cyber-Physical System Design Automation, *in: Applied Cyber-Physical Systems,* Chapter 11, p.125-140, Springer, New York

TERWIESCH C., BOHN R.E., 2001: Learning and process improvement during production ramp-up, *in: International Journal of Production Economics,* Vol. 70, p.1-19, USA

TOGAY C., 2014: Axiomatic Design Theory for Cyber-Physical Systems*, in: Applied Cyber-Physical Systems,* Chapter 8, p.85-100, Springer, New York

TSCHÖPE S., KNÜPPEL K., NYHUIS P., 2013: Assessing and Improving Ramp-Up Capability, *in: International Journal of Industrial Science and Engineering,* Vol. 7, No. 10, p.796-799, Hannover, Germany

WAN J., et.al., 2012: A general test Platform for Cyber-Physical Systems: Unmanned Vehicle with wireless sensor Network Navigation, in: *Procedia Engineering,* Vol. 24, p.123-127, Guangzhou, China

WANG K.-S., 2013: Intelligent and integrated RFID (II-RFID) system for improving traceability in manufacturing, *in: Advances in Manufacturing*, Shangai

WEISER M., GOLD R., BROWN J.S., 1999: The origins of ubiquitous computing research at PARC in the late 1980s, *in: IBM Systems Journal,* Vol. 38, No. 4, p.693-396

WESTKÄMPER E., JENDOUBI L., 2003: Smart Factories – Manufacturing environments and systems of the future*, in: The 36th CIRP-International Seminar on Manufacturing Systems*, Saarbruecken, Germany

WÜRTZ G., KÖLMEL B., 2012: Integrated Engineering – A SME-Suitable Model for Business and Information Systems Engineering (BISE) towards the Smart Factory, *in: Collaborative Networks in the Internet of Services*, p.494-502

YOON J.-S., SHIN S.-J., SUH S.-H., 2012: A conceptual framework for the ubiquitous factory, *in: International Journal of Production Research,* Vol. 50, No. 8, p.2174-2189, Republic of Korea

ZHUGE H., 2014: Cyber-Physical Society – The science and engineering for future society, *in: Future Generation Computer Systems,* Vol. 32, p.180-186, Nanjing, China

ZUEHLKE D., 2010: SmartFactory – Towards a factory-of-things*, in: Annual Reviews in Control,* Vol. 34, p.129-138, Kaiserlautern, Germany

Weblinks

Industry 4.0: Concept of the resilient factory (2014)
http://www.awk-aachen.de/__C1257B97002C1799.nsf/hatml/en_baa6222ba575fe4cc1257c730043e2bb.html [22-03-2014]

Guiding Vision
http://smartfactory.dfki.uni-kl.de/en/content/research/guidingvision [28-03-2014]

The Dawn of the Smart Factory (2013)
http://www.industryweek.com/technology/dawn-smart-factory [28-03-2014]

Internet of things (IoT) (2013)
http://www.techopedia.com/definition/28247/internet-of-things-iot [14-04-2014]

The Industry of the Future
http://www.bosch-si.com/solutions/manufacturing/industry-4-0/industry-4-0.html [15-04-2014]

About us
http://smartfactory.dfki.uni-kl.de/en/content/home/about [22-04-2014]

Members
http://smartfactory.dfki.uni-kl.de/en/content/partners/members [22-04-2014]

A revolution in Production *(*2012)
http://www.forbes.com/sites/sap/2012/08/07/a-revolution-in-production/ [23-04-2014]

Industrie 4.0: Towards an Internet of things, data and services (2013)
http://vint.sogeti.com/industrie-4-0-towards-internet-things-data-services/ [23-04-2014]

Keyfinder production line
http://smartfactory.dfki.uni-kl.de/en/content/demo/technological-demo/plant-industry4 [23-04-2014]

About the Advanced Manufacturing National Program Office; Who is part of the Advanced Manufacturing NPO?
http://www.manufacturing.gov/amnpo.html [30-04-2014]

Advanced Manufacturing Partnership Steering Committee
http://www.manufacturing.gov/amp_steering_committee.html [13-05-2014]

Digital Manufacturing & Design Innovation (DMDI) Institute
http://www.manufacturing.gov/dmdi.html [14-05-2014]

DMDI Overview
http://www.manufacturing.gov/docs/DMDI_overview.pdf [14-05-2014]

Next Generation Power Electronics National Manufacturing Innovation Institute
http://energy.gov/eere/amo/next-generation-power-electronics-national-manufacturing-innovation-institute [14-05-2014]

Next Generation Power Electronics National Manufacturing Innovation Institute
http://www.manufacturing.gov/doe-led_institutes.html [14-05-2014]

Lightweight & Modern Metals Manufacturing Innovation (LM3I) Institute
http://www.manufacturing.gov/lm3i.html [15-05-2014]

Obama Administration Launches Competition for Three New Manufacturing Innovation Institutes (2013)
http://www.whitehouse.gov/the-press-office/2013/05/09/obama-administration-launches-competition-three-new-manufacturing-innova [15-05-2014]

Festo and Insudtry 4.0 – production systems of the future
http://www.festo.com/cms/en_corp/13405.htm [20-05-2014]

Self-Organizing Factories (2013)
http://www.siemens.com/innovation/apps/pof_microsite/_pof-spring-2013/_html_en/industry-40.html [20-05-2014]

Cyber-Physical Systems
http://www.eitictlabs.eu/innovation-areas/cyber-physical-systems/ [24-05-2014]

List of Figures